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On the Values of the Constants in the Equation ${}_rA_r x^{(r)} + {}_rA_{r-1} x^{(r-1)} + \ldots + {}_rA_t x^{(t)} + \ldots + {}_rA_0 - y_x = 0$; *obtained by the method of least squares, from the* $n+1$ *values of* y_x *when* $x = 0, 1, 2, \ldots n$; n *being greater than* r. By C. Carpmael, Esq.

Suppose it known, or assumed, that the value of a quantity y_x (the approximate value of which is known when $x = 0$, and when $x = 1, 2,$ &c. $\ldots n$) may be expressed as the sum of a series of factorials of the form ${}_rA_t x^{(t)}$, where ${}_rA_t$ is the coefficient of $x^{(t)}$ when the highest factorial in the series is $x^{(r)}$.

The object of the following investigation is to determine the values of the coefficients, ${}_rA_r$ &c., which make the sum of the squares of the differences between the given values of y and those obtained from the formula a minimum.*

Now in order that

$$\Sigma_{x=0}^{x=n} ({}_rA_r x^{(r)} + {}_rA_{r-1} x^{(r-1)} + \ldots + {}_rA_t x^{(t)} + \ldots + {}_rA_0 - y_x)^2$$

may be a minimum, ${}_rA_r$ &c. must satisfy simultaneously the $r+1$ equations of the form

$${}_rA_r \Sigma_{x=0}^{x=n} x^{(r)} x^{(s)} + {}_rA_{r-1} \Sigma_{x=0}^{x=n} x^{(r-1)} x^{(s)} + \ldots + {}_rA_t \Sigma_{x=0}^{x=n} x^{(t)} x^{(s)} + \ldots + {}_rA_0 \Sigma_{x=0}^{x=n} x^{(s)} - \Sigma_{x=0}^{x=n} x^{(s)} y_x = 0,$$

s having in succession the values $r, r-1, r-2, \ldots, 0$.

The value of ${}_rA_r$ obtained from these equations is a fraction, whose denominator is a determinant of the $r+1$th order, having

$$\Sigma_{x=0}^{x=n} x^{(s)} x^{(t)}$$

* The notation is: $x^{(r)} = x\ (x-1) \ldots (x-r+1)$; $\lfloor r = 1.2.3 \ldots r$; $\Sigma_{x=0}^{x=n} y_x = y_n + y_{n-1} \ldots + y_0$.—ED.

for the constituent in its $\overline{r-s+1}$ th row and $\overline{r-t+1}$ th column; and whose numerator may be obtained from the denominator by substituting constituents of the form

$$\Sigma_{x=0}^{x=n} x^{(s)}\, y_x$$

for those of the form

$$\Sigma_{x=0}^{x=n} x^{(s)}\, x^{(r)}$$

in the first column.

Performing the summations wherever y is not involved, by aid of the formula

$$\Delta^{-1} u_x v_x = u_x \Delta^{-1} v_x - \Delta u_x \Delta^{-2} v_{x+1} + \Delta^2 u_x \Delta^{-3} v_{x+2} - \&c.,$$

we obtain for the value of the constituent in the $\overline{r-s+1}$ th row and $\overline{r-t+1}$ th column

$$\overline{n+1}^{(t)} \frac{\overline{n+1}^{(s+1)}}{\overline{s+1}} - t\,\overline{n+1}^{(t-1)} \frac{\overline{n+2}^{(s+2)}}{\overline{s+1}\;\overline{s+2}} + \ldots + (-1)^t \frac{\lfloor t \rfloor s}{\lfloor \overline{s+t+1} \rfloor} \overline{n+t+1}^{(s+t+1)}. \qquad \text{(i)}$$

In the last column $t = 0$, and (i) reduces to

$$\frac{\overline{n+1}^{(s+1)}}{\overline{s+1}};$$

in the last but one $t = 1$, and (i) becomes

$$\overline{n+1}\,\frac{\overline{n+1}^{(s+1)}}{\overline{s+1}} - \frac{\overline{n+2}^{(s+2)}}{\overline{s+1}\;\overline{s+2}};$$

and so on. Subtracting $\overline{n+1}$ times the last column from the last but one, we obtain new determinants of the same values as the previous ones, and having the constituents in the last column but one of the form

$$-\frac{\overline{n+2}^{(s+2)}}{\overline{s+1}\;\overline{s+2}}.$$

Similarly, by subtracting $2\,.\,\overline{n+1}$ times this new column, and $\overline{n+1}\,.\,n$ times the last column from the last column but two, we reduce its constituents to the form

$$2\,\frac{\overline{n+3}^{(s+3)}}{\overline{s+1}\;\overline{s+2}\;\overline{s+3}}.$$

By proceeding in this way we reduce the determinants, without

changing their values, to others having the constituents in the $\overline{r-s+1}$ th row and $\overline{r-t+1}$ th column of the form

$$(-1)^t \frac{\lfloor t \lfloor s}{\lfloor s+t+1} \overline{n+t+1}^{(s+t+1)},$$

s and t having any value from 0 to r, except in the first column of the numerator, which is left as before.

Now divide the $\overline{r-s+1}$ th row in each of these new determinants by

$$\lfloor s \, \overline{n+1}^{(s+1)},$$

and the $\overline{r-t+1}$ th column by

$$(-1)^t \frac{\lfloor t \, \overline{n+t+1}^{(t)}}{\lfloor r+t+1}.$$

This will reduce the constituent in the $\overline{r-s+1}$ th row and the $\overline{r-t+1}$ th column to the form

$$\frac{\lfloor r+t+1}{\lfloor s+t+1} \quad \text{or} \quad \overline{r+t+1}^{(r-s)},$$

except in the first column of the numerator, where the $\overline{r-s+1}$ th constituent will be

$$(-1)^r \frac{\lfloor 2r+1}{\lfloor r \, \lfloor s} \frac{\Sigma_{x=0}^{x=n} x^{(s)} y_x}{\overline{n+r+1}^{(r+s+1)}}.$$

As we here divide both the determinants by the same quantities, the value of their ratio is unchanged.

The value of ${}_rA_r$ thus obtained may be expanded in the form

$${}_rA_r = \Sigma_{s=0}^{s=r} (-1)^s \frac{\lfloor 2r+1}{\underline{r} \, \underline{\lfloor s}} \frac{1}{\overline{n+r+1}^{(r+s+1)}} {}_rR_s \, \Sigma_{x=0}^{x=n} x^{(s)} y_x, \qquad \text{(ii)}$$

where ${}_rR_s$ is of the form

$$
\begin{vmatrix}
1 & 1 & \cdots & 1 & \cdots & 1 \\
2r & 2r-1 & \cdots & r+t+1 & \cdots & r+1 \\
(2r)^{(2)} & (2r-1)^{(2)} & \cdots & (r+t+1)^{(2)} & \cdots & (r+1)^{(2)} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
(2r)^{(r-s-1)} & (2r-1)^{(r-s-1)} & \cdots & (r+t+1)^{(r-s-1)} & \cdots & (r+1)^{(r-s-1)} \\
(2r)^{(r-s+1)} & (2r-1)^{(r-s+1)} & \cdots & (r+t+1)^{(r-s+1)} & \cdots & (r+1)^{(r-s+1)} \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
(2r)^{(r)} & (2r-1)^{(r)} & \cdots & (r+t+1)^{(r)} & \cdots & (r+1)^{(r)}
\end{vmatrix}
\times
\begin{vmatrix}
1 & \cdots & 1 \\
2r & \cdots & r+1 \\
2r^{(2)} & \cdots & \overline{r+1}^{(2)} \\
\cdots & \cdots & \cdots \\
(2r)^{(r)} & \cdots & \overline{r+1}^{(r)}
\end{vmatrix}
$$

the numerator being the same as the denominator, except that the first column and $\overline{r-s+1}$ th row are wanting.

Now reverse the order of the columns, to do which will require $\frac{1}{2}r\ \overline{r-1}$ interchanges of adjacent columns in the numerator and $\frac{1}{2}r\ \overline{r+1}$ in the denominator, and will therefore alter the sign of the fraction, or not, according as $(-1)^r$ is positive or negative.

Hence

$$
{}_rR_s \equiv (-1)^r \frac{\begin{vmatrix} 1 & \cdot & \cdot & \cdot & \cdot & \cdot & 1 \\ r+1 & \cdot & \cdot & \cdot & \cdot & \cdot & 2r+1 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ (r+1)^{(r)} & \cdot & \cdot & \cdot & \cdot & \cdot & (2r+1)^{(r)} \end{vmatrix}}{\begin{vmatrix} 1 & \cdot & \cdot & \cdot & \cdot & \cdot & 1 \\ r+1 & \cdot & \cdot & \cdot & \cdot & \cdot & 2r+1 \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ (r+1)^{(r)} & \cdot & \cdot & \cdot & \cdot & \cdot & (2r+1)^{(r)} \end{vmatrix}} \quad \text{(iii)}
$$

In the determinants in (iii) from each column, beginning at the right, subtract that next to its left; the determinants will thus be each reduced one order lower, for the constituents of the first row are all reduced to zero, except the first, which remains unity. Then divide each row by the factor common to that row. These common factors are the same in both numerator and denominator, except that one factor $\overline{r-s}$ occurs in the denominator and not in the numerator. The value of ${}_rR_s$ is now reduced to the form

$$\frac{(-1)^r}{r-s}\begin{vmatrix} 1 & \dots & 1 \\ r+1 & \dots & 2r-1 \\ \vdots & & \vdots \\ (r+1)^{(r-s-2)} & \dots & (2r-1)^{(r-s-2)} \\ (r+1)^{(r-s)} & \dots & (2r-1)^{(r-s)} \\ \vdots & & \vdots \\ (r+1)^{(r-1)} & \dots & (2r-1)^{(r-1)} \end{vmatrix}$$

$$\begin{vmatrix} 1 & \dots & 1 \\ r+1 & \dots & 2r \\ \vdots & & \vdots \\ (r+1)^{(r-s-1)} & \dots & (2r)^{(r-s-1)} \\ \vdots & & \vdots \\ (r+1)^{(r-1)} & \dots & (2r)^{(r-1)} \end{vmatrix}$$

where the determinants are similar in form to those in (iii) but one order lower, and the missing row in the numerator is now that containing factorials of $r-s-1$ factors.

Repeat the reduction in this way $r-s$ times, including that already performed, then the value of ${}_rR_s$ will be reduced to the form

$$\frac{(-1)^r}{\lfloor r-s}\begin{vmatrix} r+1 & r+2 & \dots & r+s \\ (r+1)^{(2)} & (r+2)^{(2)} & \dots & (r+s)^{(2)} \\ \vdots & \vdots & & \vdots \\ (r+1)^{(s)} & (r+2)^{(s)} & \dots & (r+s)^{(s)} \end{vmatrix}$$

$$\begin{vmatrix} 1 & 1 & \dots & 1 \\ r+1 & r+2 & \dots & r+s+1 \\ (r+1)^{(2)} & (r+2)^{(2)} & \dots & (r+s+1)^{(2)} \\ \vdots & \vdots & & \vdots \\ (r+1)^{(s)} & (r+2)^{(s)} & \dots & (r+s+1)^{(s)} \end{vmatrix}$$

The determinants have now been reduced $r-s$ orders lower than at first, and the row of the denominator which is missing in the numerator is that in which every constituent is unity.

Taking out the factors in the numerator which occur throughout any column, we get

$$ {}_rR_s = (-1)^r \frac{\lfloor r+s}{\lfloor r \lfloor r-s} \frac{\begin{pmatrix} 1 & \dots & 1 \\ r & \dots & r+s-1 \\ \vdots & & \vdots \\ r^{(s-1)} & \dots & (r+s-1)^{(s-1)} \end{pmatrix}}{\begin{pmatrix} 1 & \dots & 1 \\ r+1 & \dots & r+s+1 \\ \vdots & & \vdots \\ (r+1)^{(s)} & \dots & (r+s+1)^{(s)} \end{pmatrix}} $$

The row now missing in the numerator is the last, and in the numerator r occurs instead of $r+1$.

Reduce the order of the determinants in the same way as before, s times, we get

$$ {}_rR_s = (-1)^r \frac{\lfloor r+s}{\lfloor r \lfloor s \lfloor r-s}. $$

Substituting this value for ${}_rR_s$ in (ii), we get for the value of ${}_rA_r$

$$ A_r = \Sigma_{s=0}^{s=r} (-1)^{r+s} \frac{\lfloor 2r+1}{(\lfloor r \lfloor s)^2} \frac{\lfloor r+s}{\lfloor r-s} \frac{1}{(n+r+1)^{(r+s+1)}} \Sigma_{x=0}^{x=n} x^{(s)} y_x. \qquad (A) $$

From this formula we can without much labour determine the coefficient, in any numerical example, of the highest factorial in the expression for y.

The values of the remaining coefficients are most easily obtained by an indirect method, as follows :—

Let ${}_rB_\rho$ be the value of ${}_rA_r$ when $x^{(\rho)}$ is substituted for y_x, then

$$ {}_rB_\rho = \Sigma_{s=0}^{s=r} (-1)^{r+s} \frac{\lfloor 2r+1}{(\lfloor r \lfloor s)^2} \frac{\lfloor r+s}{\lfloor r-s} \frac{1}{(n+r+1)^{(r+s+1)}} \Sigma_{x=0}^{x=n} x^{(s)} x^{(\rho)}. $$

Now by aid of the formula

$$ \Delta^{-1} u_x v_x = u_{x-1} \Delta^{-1} v_x - \Delta u_{x-2} \Delta^{-2} v_x + \&c., $$

we have

$$\Sigma_{x=0}^{x=n} x^{(s)}\, x^{(\rho)} = n^{(s)}\,\frac{(n+1)^{(\rho+1)}}{\rho+1} - s\,(n-1)^{(s-1)}\,\frac{(n+1)^{(\rho+2)}}{(\rho+1)\,(\rho+2)} + \ldots$$
$$+ (-1)^p\,\frac{\lfloor s}{\lfloor s-p}\,(n-p)^{(s-p)}\,\frac{\lfloor \rho}{\lfloor \rho+p+1}\,(n+1)^{(\rho+p+1)} + \&c.$$

Hence ${}_rB_\rho$ may be written in the form

$$\Sigma_{s=0}^{s=r}\,\frac{\lfloor 2r+1}{(\lfloor r)^2}\,\frac{\lfloor r+s}{\lfloor r-s}\,\frac{1}{(n+r+1)^{(r+s+1)}}\,\Sigma_{p=0}^{p=s}\,\frac{\lfloor s}{\lfloor s-p}\,\frac{\lfloor n-p}{\lfloor n-s}\,\frac{\lfloor \rho}{\lfloor \rho+p+1}\,(n+1)^{(\rho+p+1)}\,(-1)^{p+r+s};$$

or

$$\Sigma_{s=0}^{s=r}\,\Sigma_{p=0}^{p=s}\,(-1)^{p+r+s}\,\frac{\lfloor 2r+1}{(\lfloor r)^2\,\lfloor n+r+1}\,\frac{\lfloor r+s}{\lfloor s\,\lfloor r-s\,\lfloor s-p}\,\frac{\lfloor n-p\,\lfloor \rho\,\lfloor n+1}{\lfloor \rho+p+1\,\lfloor n-\rho-p};$$

or, changing the order of the summations,

$${}_rB_\rho = \Sigma_{p=0}^{p=r}\,\Sigma_{s=p}^{s=r}\,(-1)^{p+r+s}\,\frac{\lfloor 2r+1}{(\lfloor r)^2\,\lfloor n+r+1}\,\frac{\lfloor n-p\,\lfloor \rho\,\lfloor n+1}{\lfloor \rho+p+1\,\lfloor n-\rho-p}\,\frac{\lfloor r+s}{\lfloor s\,\lfloor r-s\,\lfloor s-p}.$$

Now

$$\frac{\lfloor r+s}{\lfloor s} \text{ is } = \text{ coeff. of } x^s \text{ in expansion of } \lfloor r\,(1-x)^{-r-1},$$

and

$$(-1)^{r\pm s}\,\frac{1}{\lfloor r-s\,\lfloor s-p} \text{ is } = \text{ coeff. of } x^{r-s} \text{ in expansion of } \frac{(1-x)^{r-p}}{\lfloor r-p},$$

when s has any value from $s=p$ to $s=r$; therefore

$$\Sigma_{s=p}^{s=r}\,(-1)^{r+s}\,\frac{\lfloor r+s}{\lfloor s}\,\frac{1}{\lfloor r-s\,\lfloor s-p}$$

is $=$ coeff. of x^r in expansion of

$$\frac{\lfloor r}{\lfloor r-p}\,(1-x)^{-p-1},$$

that is, it is $=$

$$\frac{\lfloor r}{\lfloor r-p}\,\frac{\lfloor r+p}{\lfloor r\,\lfloor p} \quad \text{or} \quad \frac{\lfloor r+p}{\lfloor r-p\,\lfloor p}.$$

Hence

$${}_rB_\rho = \Sigma_{p=0}^{p=r}\,(-1)^p\,\frac{\lfloor 2r+1}{(\lfloor r)^2}\,\frac{\lfloor \rho\,\lfloor n+1}{\lfloor n+r+1}\,\frac{\lfloor n-p\,\lfloor r+p}{\lfloor \rho+p+1\,\lfloor n-\rho-p\,\lfloor r-p\,\lfloor p},$$

which may be written

$${}_rB_\rho = \frac{\lfloor 2r+1}{(\lfloor r)^3}\,\frac{\lfloor n+1\,\lfloor \rho}{\lfloor n+r+1}\left(1-\frac{E'}{E}\right)^r n^{(\rho)}\,(r+1)^{(-\rho+r-1)},$$

where

E′ applies only to $(r+1)^{(-\rho+r-1)}$ and $\mathrm{E}'\,(r+1)^{(-\rho+r-1)} = (r+2)^{(-\rho+r-1)}$,

and

E applies only to $n^{(\rho)}$ and $\mathrm{E}\,n^{(\rho)} = (n+1)^{(\rho)}$.

Hence

$$ {}_rB_\rho = \frac{\lfloor 2r+1 \rfloor \lfloor n+1 \rfloor \lfloor \rho}{(\lfloor r)^3 \lfloor n+r+1}\left(\frac{\Delta-\Delta'}{\mathrm{E}}\right)^r n^{(\rho)}\,(r+1)^{(-\rho+r-1)}, $$

$$ = \frac{\lfloor 2r+1 \rfloor \lfloor n+1 \rfloor \lfloor \rho}{(\lfloor r)^3 \lfloor n+r+1}\,\Sigma_{p=0}^{p=r}\frac{\lfloor r\,(-1)^{r-p}}{\lfloor p \lfloor r-p}\,\Delta^p\,(n-r)^{(\rho)}\,\Delta'^{r-p}\,(r+1)^{(-\rho+r-1)}, $$

$$ = \frac{\lfloor 2r+1 \rfloor \lfloor n+1 \rfloor \lfloor \rho}{(\lfloor r)^3 \lfloor n+r+1}\,\Sigma_{p=0}^{p=r}\frac{\lfloor r}{\lfloor p \lfloor r-p}\,\rho^{(p)}\,(n-r)^{(\rho-p)}\,\frac{\lfloor \rho-p}{\lfloor \rho-r}\,(r+1)^{(-\rho+p-1)}, $$

$$ = \frac{\lfloor 2r+1 \rfloor \lfloor n-r}{\lfloor n+r+1 \rfloor \rho-r}\left(\frac{\lfloor \rho}{\lfloor r}\right)^2 \Sigma_{p=0}^{p=r}\frac{\lfloor n+1}{\lfloor n-r-\rho+p \rfloor r+\rho-p+1}\,\frac{\lfloor r}{\lfloor p \lfloor r-p}. $$

Now

$$ \frac{\lfloor n+1}{\lfloor n-r-\rho+p \rfloor r+\rho-p+1} \text{ is } = \text{ coeff. of } x^{r+\rho-p+1} \text{ in expansion of } (1+x)^{n+1}, $$

and

$$ \frac{\lfloor r}{\lfloor p \lfloor r-p} \text{ is } = \text{ coeff. of } x^p \text{ in expansion of } (1+x)^r; $$

therefore

$$ \Sigma_{p=0}^{p=r}\frac{\lfloor n+1 \lfloor r}{\lfloor n-r-\rho+p \rfloor r+\rho-p+1 \lfloor p \lfloor r-p} $$

is $=$ coeff. of $x^{r+\rho+1}$ in the expansion of $\overline{1+x}^{n+r+1}$, and is therefore

$$ = \frac{\lfloor n+r+1}{\lfloor r+\rho+1 \lfloor n-\rho}; $$

Hence

$$ {}_rB_\rho = \frac{\lfloor n-r \lfloor 2r+1}{\lfloor r+\rho+1 \lfloor n-\rho \lfloor \rho-r}\left(\frac{\lfloor \rho}{\lfloor r}\right)^2, $$

$$ = \frac{\overline{(n-r)}^{(\rho-r)}}{(r+\rho+1)^{(\rho-r)}}\,\frac{\{\rho^{(\rho-r)}\}^2}{\lfloor \rho-r}. \qquad \text{(iv)} $$

Now the original equations for finding ${}_rA_r$, ${}_rA_{r-1}$, &c. may be written

$$ {}_rA_t \Sigma_{x=0}^{x=n} x^{(t)}\, x^{(s)} + {}_rA_{t-1} \Sigma_{x=0}^{x=n} x^{(t-1)}\, x^{(s)} \ldots $$

$$ + {}_rA_0 \Sigma_{x=0}^{x=n} x^{(s)} - \Sigma_{x=0}^{x=n} x^{(s)} \left(y_x - {}_rA_r\, x^{(r)} - \ldots - {}_rA_{t+1}\, x^{(t+1)}\right) = 0 ; $$

so that when

$$ {}_rA_r,\ {}_rA_{r-1} \ldots {}_rA_{t+1} $$

have been determined, ${}_rA_t$ may be obtained in the manner that ${}_rA_r$ was, but with

$$ y_x - {}_rA_r\, x^{(r)} - \ldots - {}_rA_{t+1}\, x^{(t+1)} $$

written for y_x.

Hence by (A)

$$ {}_rA_t = \Sigma_{s=0}^{s=t} (-1)^{s+t} \frac{\lfloor 2t+1}{\lfloor t\ \lfloor s)^2} \frac{\lfloor t+s}{\lfloor t-s} \frac{1}{(n+t+1)^{(s+t+1)}} \times $$

$$ \Sigma_{x=0}^{x=n} x^{(s)} \left\{ y_x - {}_rA_r\, x^{(r)} - \ldots - {}_rA_p\, x^{(p)} - \ldots - {}_rA_{t+1}\, x^{(t+1)} \right\} $$

$$ = {}_tA_t - {}_tB_r \cdot {}_rA_r - {}_tB_{r-1} \cdot {}_rA_{r-1} - \ldots - {}_tB_p \cdot {}_rA_p - \ldots {}_tB_{t+1} \cdot {}_rA_{t+1} $$

$$ = {}_tA_t - \Sigma_{p=t+1}^{p=r} {}_tB_p \cdot {}_rA_p, $$

$$ = {}_tA_t - \Sigma_{p=t+1}^{p=r} \frac{(n-t)^{(p-t)} \left\{ p^{(p-t)} \right\}^2}{(t+p+1)^{(p-t)}\ \lfloor p-t} {}_rA_p. \qquad \text{(v)} $$

Suppose $t = r-1$, then by (v)

$$ {}_rA_{r-1} = {}_{r-1}A_{r-1} - \frac{n-r+1}{2r} r^2\, {}_rA_r. $$

Similarly, if in (v) t be put equal to $r-2$, we get

$$ {}_rA_{r-2} = {}_{r-2}A_{r-2} - \frac{n-r+2}{2r-2} (r-1)^2 \left\{ {}_{r-1}A_{r-1} - \frac{n-r+1}{2r} r^2\, {}_rA_r \right\} $$

$$ - \frac{(n-r+2)^{(2)}}{(2r-1)^{(2)}} \frac{\left\{ r^{(2)} \right\}^2}{\lfloor 2} {}_rA_r, $$

$$ = {}_{r-2}A_{r-2} - \frac{n-r+2}{2(r-1)} (r-1)^2\, {}_{r-1}A_{r-1} + \frac{(n-r+2)^{(2)} \left\{ r^{(2)} \right\}^2}{2\,(2r)^{(2)}} {}_rA_r. $$

In the same way if t be put equal to $r-3$ in (v), it will be found that the resulting equation may be reduced to the form

$$ {}_rA_{r-3} = {}_{r-3}A_{r-3} - \frac{n-r+3}{2r-4} (r-2)^2\, {}_{r-2}A_{r-2} $$

$$ + \frac{(n-r+3)^{(2)}}{\lfloor 2} \frac{\left\{ (r-1)^{(2)} \right\}^2}{(2r-2)^{(2)}} {}_{r-1}A_{r-1} - \frac{(n-r+3)^{(3)} \left\{ r^{(3)} \right\}^2}{\lfloor 3\ (2r)^{(3)}} {}_rA_r. $$

We see then that as far as ${}_rA_{r-3}$ the value of ${}_rA_s$ is of the form

$$\Sigma_{t=s}^{t=r} (-1)^{s+t} \frac{(n-s)^{(t-s)}\{t^{(t-s)}\}^2}{(2t)^{(t-s)}\ \underline{|t-s}}\ {}_tA_t. \qquad (B)$$

Let us assume that all the coefficients ${}_rA_{r-1}, {}_rA_{r-2} \ldots {}_rA_s$ are of this form; we will prove that ${}_rA_{s-1}$ must also be of this form.

For by (v)

$${}_rA_{s-1} = {}_{s-1}A_{s-1} - \Sigma_{p=s}^{p=r} \frac{(n-s+1)^{(p-s+1)}\{p^{(p-s+1)}\}^2}{(s+p)^{(p-s+1)}\ \underline{|p-s+1}}\ {}_rA_p$$

$$= {}_{s-1}A_{s-1} - \Sigma_{p=s}^{p=r} \frac{(n-s+1)^{(p-s+1)}\{p^{(p-s+1)}\}^2}{(s+p)^{(p-s+1)}\ \underline{|p-s+1}}\ \Sigma_{t=p}^{t=r} (-1)^{p+t} \frac{(n-p)^{(t-p)}\{t^{(t-p)}\}^2}{(2t)^{(t-p)}\ \underline{|t-p}}\ {}_tA_t$$

(for, by hypothesis, B holds for all values of from s to r); therefore

$${}_rA_{s-1} = {}_{s-1}A_{s-1} - \Sigma_{p=s}^{p=r}\ \Sigma_{t=p}^{t=r} (-1)^{p+t} \frac{(n-s+1)^{(t-s+1)}\{t^{(t-s+1)}\}^2}{(2t)^{(t-p)}\ \underline{|t-p}\ (s+p)^{(p-s+1)}\ \underline{|p-s+1}}\ {}_tA_t;$$

or, changing the order of the summations,

$${}_rA_{s-1} = {}_{s-1}A_{s-1} - \Sigma_{t=s}^{t=r}\ \Sigma_{p=s}^{p=t} (-1)^{p+t} \frac{(n-s+1)^{(t-s+1)}\{t^{(t-s+1)}\}^2}{(2t)^{(t-p)}\ \underline{|t-p}\ (s+p)^{(p-s+1)}\ \underline{|p-s+1}}\ {}_tA_t.$$

Now

$$\frac{\underline{|t-s+1}}{\underline{|t-p}\ \underline{|p-s+1}} \text{ is } = \text{ coeff. of } x^{t-p} \text{ in expansion of } (1+x)^{t-s+1},$$

and

$$(-1)^{p+s} \frac{\underline{|t+p}}{\underline{|t-s}\ \underline{|p+s}} \text{ is } = \text{ coeff. of } x^{p+s} \text{ in expansion of } (1+x)^{-t+s-1};$$

Hence

$$\Sigma_{p=s-1}^{p=t} (-1)^{p+s} \frac{\underline{|t-s+1}}{\underline{|t-p}\ \underline{|p-s+1}} \frac{\underline{|t+p}}{\underline{|t-s}\ \underline{|p+s}}$$

is equal to the coefficient of x^{t+s} in the expansion of $(1+x)^0$ and is therefore zero. Hence

$$\Sigma_{p=s}^{p=t} (-1)^{p+s} \frac{\underline{|t+p}}{\underline{|t-p}\ \underline{|p-s+1}\ \underline{|p+s}} = \frac{\underline{|t+s-1}}{\underline{|t-s+1}\ \underline{|2s-1}};$$

or, finally,

$${}_rA_{s-1} = {}_{s-1}A_{s-1} - \Sigma_{t=s}^{t=r} (-1)^{s+t} \frac{(n-s+1)^{(t-s+1)}\{t^{(t-s+1)}\}^2}{\underline{|2t}}\ \underline{|2s-1}\ \frac{\underline{|t+s-1}}{\underline{|t-s+1}\ \underline{|2s-1}}\ {}_tA_t,$$

$$= \Sigma_{t=s-1}^{t=r} (-1)^{s+t-1} \frac{(n-s+1)^{(t-s+1)}\{t^{(t-s+1)}\}^2}{(2t)^{t-s+1}\ \underline{|t-s+1}}\ {}_tA_t,$$

which is of the form (B) with $s-1$ in place of s.

But ${}_rA_{r-1}$, ${}_rA_{r-2}$ have been already shown to be of the form (B), so therefore is ${}_rA_{r-3}$, and so then ${}_rA_{r-4}$ &c. Hence, for all values of s from $s = 0$ to $s = r-1$, ${}_rA_s$ is of the form given by (B).

The result of the foregoing investigation may be thus stated: If ${}_rA_s$ be the coefficient of $x^{(s)}$ obtained, by the method of least squares, from the $n+1$ values of y_x when $x = 0, 1, 2, \ldots n$, n being greater than r, and y_x being of the form

$${}_rA_r\, x^{(r)} + {}_rA_{r-1}\, x^{(r-1)} + \ldots + {}_rA_s\, x^{(s)} + \ldots + {}_rA_0;$$

then

$$A_s = \Sigma_{t=s}^{t=r} (-1)^{t+s} \frac{(n-s)^{(t-s)} \{t^{(t-s)}\}^2}{(2t)^{(t-s)} \lfloor t-s} \, {}_tA_t, \qquad \text{(B)}$$

where

$${}_tA_t = \Sigma_{\rho=0}^{\rho=t} (-1)^{\rho+t} \frac{\lfloor 2t+1}{(\lfloor t \lfloor \rho)^2} \frac{(t+\rho)^{(2\rho)}}{(n+t+1)^{(t+\rho+1)}} \Sigma_{x=0}^{x=n} x^{(\rho)}\, y_x. \qquad \text{(A)}$$

The following are the values of the constants, calculated from these formulæ, as far as they are required if fifth differences are assumed to be constant.

$$_0A_0 = \frac{1}{n+1} \Sigma_{x=0}^{x=n} y_x.$$

$$_1A_1 = \frac{-6}{(n+2)(n+1)} \Sigma_{x=0}^{x=n} y_x + \frac{12}{(n+2)(n+1)n} \Sigma_{x=0}^{x=n} x\, y_x.$$

$$_2A_2 = \frac{30}{(n+3)(n+2)(n+1)} \Sigma_{x=0}^{x=n} y_x - \frac{180}{(n+3)(n+2)(n+1)n} \Sigma_{x=0}^{x=n} x\, y_x + \frac{180}{(n+3)(n+2)\ldots(n-1)} \Sigma_{x=0}^{x=n} x(x-1)\, y_x.$$

$$_3A_3 = \frac{-140}{(n+4)(n+3)\ldots(n+1)} \Sigma_{x=0}^{x=n} y_x + \frac{1680}{(n+4)(n+3)\ldots n} \Sigma_{x=0}^{x=n} x\, y_x - \frac{4200}{(n+4)(n+3)\ldots(n-1)} \Sigma_{x=0}^{x=n} x(x-1)\, y_x + \frac{2800}{(n+4)(n+3)\ldots(n-2)} \Sigma_{x=0}^{x=n} x(x-1)(x-2)\, y_x.$$

$$_4A_4 = \frac{630}{(n+5)(n+4)\ldots(n+1)} \Sigma_{x=0}^{x=n} y_x - \frac{12600}{(n+5)(n+4)\ldots n} \Sigma_{x=0}^{x=n} x\, y_x + \frac{56700}{(n+5)(n+4)\ldots(n-1)} \Sigma_{x=0}^{x=n} x(x-1)\, y_x - \frac{88200}{(n+5)(n+4)\ldots(n-2)} \Sigma_{x=0}^{x=n} x(x-1)(x-2)\, y_x + \frac{44100}{(n+5)(n+4)\ldots(n-3)} \Sigma_{x=0}^{x=n} x(x-1)(x-2)(x-3)\, y_x.$$

$$_5A_5 = \frac{-2772}{(n+6)(n+5)\ldots(n+1)} \Sigma_{x=0}^{x=n} y_x + \frac{83160}{(n+6)(n+5)\ldots n} \Sigma_{x=0}^{x=n} x\, y_x - \frac{582120}{(n+6)(n+5)\ldots(n-1)} \Sigma_{x=0}^{x=n} x(x-1)\, y_x + \frac{1552320}{(n+6)(n+5)\ldots(n-2)} \Sigma_{x=0}^{x=n} x(x-1)(x-2)\, y_x - \frac{1746360}{(n+6)(n+5)\ldots(n-3)} \Sigma_{x=0}^{x=n} x(x-1)(x-2)(x-3)\, y_x + \frac{698544}{(n+6)(n+5)\ldots(n-4)} \Sigma_{x=0}^{x=n} x(x-1)(x-2)(x-3)(x-4)\, y_x.$$

$$ {}_nA_0 = {}_0A_0 - \frac{n}{2}\,{}_1A_1 + \frac{n(n-1)}{6}\,{}_2A_2 - \frac{n(n-1)(n-2)}{20}\,{}_3A_3 + \frac{n(n-1)(n-2)(n-3)}{70}\,{}_4A_4 - \frac{n(n-1)(n-2)(n-3)(n-4)}{252}\,{}_5A_5 + \&c. $$

$$ {}_nA_1 = {}_1A_1 - (n-1)\,{}_2A_2 + \frac{3}{5}(n-1)(n-2)\,{}_3A_3 - \frac{2}{7}(n-1)(n-2)(n-3)\,{}_4A_4 + \frac{5}{42}(n-1)(n-2)(n-3)(n-4)\,{}_5A_5 - \&c. $$

$$ {}_nA_2 = {}_2A_2 - \frac{3}{2}(n-2)\,{}_3A_3 + \frac{9}{7}(n-2)(n-3)\,{}_4A_4 - \frac{5}{6}(n-2)(n-3)(n-4)\,{}_5A_5 + \&c. $$

$$ {}_nA_3 = {}_3A_3 - 2(n-3)\,{}_4A_4 + \frac{20}{9}(n-3)(n-4)\,{}_5A_5 - \&c. $$

$$ {}_nA_4 = {}_4A_4 - \frac{5}{2}(n-4)\,{}_5A_5 + \&c. $$

If fourth differences are assumed constant, ${}_5A_5$ must be put equal to zero; if third differences are taken as constant, ${}_4A_4$ and ${}_5A_5$ must be put equal to zero; and so on.

In employing these formulæ, it will generally save labour if we subtract from each of the quantities y_x the quantity given by the formula

$$C_r x^{(r)} + C_{r-1} x^{(r-1)} + \ldots + C_s x^{(r)} + \ldots + C_0,$$

where C_r, C_{r-1}, ... C_0 are so chosen as to make

$$y_x - (C_r x^{(r)} + C_{r-1} x^{(r-1)} + \ldots + C_0) = 0$$

for all values of x from $x = n-r$ to $x = n$. Thus all the values of y_x for which the coefficient is large will vanish, and the other values will also, as a rule, be very much diminished. The formulæ (A) and (B) may then be employed, using the remainders, after subtraction, instead of the original values of y_x; and if ${}_rA'_s$ is one of the coefficients so determined, the coefficient in the original value of y_x will be

$$C_s + {}_rA'_s.$$

The above investigation may also be modified, so as to apply to the case when the coefficients in the value for y_x are known to be connected by one or more linear relations, and also for approximating to the values when the relations are not linear.

For, suppose it known that

$$a_r \cdot {}_rA_r + a_{r-1} \cdot {}_rA_{r-1} + \ldots + a_\rho \cdot {}_rA_\rho + \ldots + a_0 \cdot {}_rA_0 + q = 0, \qquad \text{(vi)}$$

we must make

$$\Sigma_{x=0}^{x=n} ({}_rA_r x^{(r)} + {}_rA_{r-1} x^{(r-1)} + \ldots + {}_rA_\rho x^{(\rho)} + \ldots + {}_rA_0 - y_x)^2$$
$$- \lambda (a_r \cdot {}_rA_r + a_{r-1} \cdot {}_rA_{r-1} + \ldots + a_\rho \cdot {}_rA_\rho + \ldots + a_0 \cdot {}_rA_0 + q)$$

a minimum.

The resulting equations are of the same form as before, except that now

$$\lambda a_\rho + \Sigma_{x=0}^{x=n} x^{(\rho)} y_x$$

occurs instead of

$$\Sigma_{x=0}^{x=n} x^{(\rho)} y_x,$$

ρ having any value from 0 to r.

Replacing

$$\Sigma_{x=0}^{x=n} x^\rho y_x \text{ by } \lambda a_\rho + \Sigma_{x=0}^{x=n} x^{(\rho)} y_x$$

in the solution, we get

$$ {}_tA_t = \Sigma_{\rho=0}^{\rho=t} (-1)^{\rho+t} \frac{|2t+1}{(\underline{|t}\ \underline{|\rho})^2} \frac{(t+\rho)^{(2\rho)}}{(n+t+1)^{(t+\rho+1)}} \{\lambda\, a_\rho + \Sigma_{x=0}^{x=n}\, x^{(\rho)}\, y_x\}; \qquad \text{(vii)} $$

whence ${}_rA_s$ &c. may be determined in terms of λ. The value of λ must then be determined, so that (vi) is satisfied; and this value must then be substituted in the expressions for ${}_rA_s$, &c.

If the relation be not linear, suppose ϕ (${}_rA_r$, ${}_rA_{r-1}$, &c.) be the relation.

Let ${}_rA'_r$, ${}_rA'_{r-1}$, &c. be the values of the constants found by means of (A) and (B) without reference to the given relation. Suppose ${}_rA_r = {}_rA'_r + \delta\, {}_rA'_r$ &c., then

$$ \phi\,({}_rA'_r + \delta\, {}_rA'_r,\ {}_rA'_{r-1} + \delta\, {}_rA'_{r-1},\ \&c.) = 0; $$

therefore

$$ \phi\,({}_rA'_r,\ {}_rA'_{r-1},\ \&c.) + \delta\, {}_rA'_r \frac{d\,\phi}{d\,{}_rA'_r} + \delta\, {}_rA'_{r-1} \frac{d\,\phi}{d\,{}_rA'_{r-1}} + \&c. = 0, $$

or

$$ {}_rA_r \frac{d\,\phi}{d\,{}_rA'_r} + {}_rA_{r-1} \frac{d\,\phi}{d\,{}_rA'_{r-1}} + \ldots + \phi\,({}_rA'_r,\ {}_rA'_{r-1},\ \&c.) - {}_rA'_r \frac{d\,\phi}{d\,{}_rA'_r} - {}_rA'_{r-1} \frac{d\,\phi}{d\,{}_rA'_{r-1}} + \&c. = 0. $$

If we suppose that $\delta\, {}_rA_r$ &c. are so small that their squares and products may be neglected, then $\frac{d\,\phi}{d\,{}_rA'_r}$ &c. may be treated as constants; the relation will now be of the form (vi) and we may find as above the values of ${}_rA_r$, ${}_rA_{r-1}$, &c.

Meteorological Office, Toronto, Canada,
1879, *April* 30.

Royal Observatory, Greenwich,
1879, *July* 29.

It is known generally to the Society that meridional observations on a comprehensive scale are carried on at the Royal Observatory with unceasing regularity; but it is not so generally known that a considerable number of extrameridional or irregular observations have accumulated during my superintendence of the Observatory.

I have thought, therefore, that I might with propriety lay before the Society an arranged list of observations of the last-mentioned classes, nearly the whole of which are included in the annual volumes of *Greenwich Observations*.

G. B. Airy.

Index to the Records of occasional Observations and Calculations made at the Royal Observatory, Greenwich, and to other miscellaneous Papers connected with that Institution, not comprehended in the ordinary routine of the Observatory, but printed in the Annual Volumes of the Greenwich Observations, from 1836, *January, to* 1875, *December; with List of other Publications of the Royal Observatory.*

List of Subjects of the Papers.

I. Regulations of the Royal Observatory.
II. Plans of the Buildings and Grounds.
III. Descriptions of Instruments.
IV. Auxiliary Tables and New Methods.
V. Results of Earlier Observations.
VI. Catalogues of Principal Stars.
VII. Observations with the Water-Telescope.
VIII. Measures of Double Stars with the Double-image Micrometer.
IX. Observations for a Star's Proper Motion and Parallax.
X. Variations of Brightness and Spectroscopy of Stars.
XI. Micrometric Observations of Solar Eclipses, with complete Reductions.
XII. Observations of Lunar Eclipses.
XIII. Comparisons of Lunar Tables with Observations.
XIV. Extra-meridional Transits of the Moon for Measure of Diameter.
XV. Deduction of the Moon's Diameter from observed Occultations.
XVI. Lunar Theory.
XVII. Reduction of Ancient Observations of Planets.
XVIII. Corrections of the Orbital Elements in the Tables of *Jupiter* and *Saturn*.
XIX. Transits of *Mercury* over the Sun's Disk.
XX. Equatoreal Observations of *Mars*, East and West of Meridian, for Solar Parallax.
XXI. Occultations of Planets by the Moon.
XXII. Comparisons of the Places of Planets with those of neighbouring Stars, by Equatoreal.
XXIII. Measures of the Diameters of Planets and of *Saturn's* Ring, with the Double-image Micrometer.
XXIV. Remarks on the Surfaces of Planets.
XXV. Measures of the Positions of Satellites relative to their Primaries.
XXVI. Equatoreal Comparisons of the Places of Comets with Stars, and Remarks on the Appearance of Comets.
XXVII. Operations for Terrestrial Longitude.
XXVIII. Ancient Magnetic Observations.
XXIX. Lithographic Copies of Photographic Records made by Magnetical and Meteorological Instruments.
XXX. Reductions of Modern Magnetic Observations.
XXXI. Barometric Variations.
XXXII. Observations of Thermometers sunk deep in the ground.
XXXIII. Observations of an Earthquake.

The following account of the routine system of the Royal Observatory, commencing from 1836, may be conveniently premised to the Index.

The meridional astronomical observations were made from 1836 to 1850, with Troughton's Transit and Troughton's and

Jones's Circles; and from the beginning of 1851 with the Transit-Circle.

The observations of γ *Draconis* were made with Troughton's Zenith-Tube from 1836 to 1848, and with the Reflex Zenith-Tube from 1851 (first printed in the volume for 1852).

The Altazimuth observations began in May 1847. Observations with the South-east Equatoreal began in 1860.

Meridional and Altazimuth observations, occultations of stars, &c. by the Moon, and phenomena of *Jupiter's* satellites, are completely reduced as far as possible; each in the volume of *Observations* for its year.

The magnetical and meteorological observations from 1843 to 1847 were printed in separate annual volumes. From 1848 they are printed (in a less extended form) in the *Greenwich Observations.*

Reports on trials of chronometers began in 1841.

Reports to the Board of Visitors began in 1836, and were first printed in the *Observations* 1838.

INDEX.

Volume of *Greenwich Observations.*

Subject of the Papers &c.

I.—Regulations of the Royal Observatory.

1852. First edition of the Regulations.
1873. Second edition of the Regulations.

II.—Plans of the Buildings and Grounds.

1845. First Plan.
1862. Second Plan.

III.—Descriptions of Instruments.

... (The description and the theory of the double-image micrometer are given: for the first form, in the Royal Astronomical Society's *Memoirs*, volume xv., 1845; and for the second or Valz's form, in the *Monthly Notices*, 1850, June 14.)
1847. (Introduction). Description of the Altazimuth.
1852. Description of the Transit-Circle.
1854. Description of the Reflex Zenith-Tube.
1856. Description of the Chronograph.
1867. Description of the Altazimuth. (Reprint.)
1867. Description of the Transit-Circle. (Reprint.)
1868. Description of the Great Equatoreal.

IV.—Auxiliary Tables and New Methods.

1836. Bessel's Refraction Tables, in altered form.
1836. Factors for converting Errors of R.A. and N.P.D. into Errors of Longitude and E. N.P.D.
1837. Logarithms of Sines and Cosines to every ten seconds of time through the twenty-four hours.
1837. Tables for converting Sidereal Time into Mean Solar Time.
... (The method of computing star corrections without use of algebraic signs is given in the Royal Astronomical Society's *Memoirs*, vol. xvi., 1847.)

Vol. of *G.O.*

1847. Repetition of the method above mentioned.
1847. Day numbers for the application of that method, from 1849 to 1860. (For subsequent years these numbers are given in the *Nautical Almanac*.)
1853. Bessel's Refraction Tables, modified and expanded.
1854. Factors for converting Errors of Azimuth and Zenith Distance into Errors of R.A. and N.P.D.
... (The method of computing interpolations to the second order without changes of algebraic signs is given in the *Monthly Notices*, 1866, April 13.)

V.—Results of Earlier Observations.

1851. Results of the observations of the principal stars made and reduced by Dr. Maskelyne: including determinations of the Equinoxes, of the R.A. of the principal stars, of the Z.D. of γ *Draconis* with Zenith Sector and Quadrant, and of other principal stars with Quadrant, 1765 to 1811. (From Dr. Maskelyne's manuscripts.)

VI.—Catalogues of Principal Stars.

1842. Catalogue of 1439 stars for 1840.
1847. Catalogue of 2156 stars for 1840 and for 1845. (Twelve-year Catalogue.)
1854. Catalogue of 1576 stars for 1850. (Six-year Catalogue.)
1856. Corrections of Secular Variations in the two last-mentioned Catalogues.
1862. Catalogue of 2022 stars for 1860. (First Seven-year Catalogue.)
1868. Catalogue of 2760 stars for 1864. (Second Seven-year Catalogue.)

VII.—Observations with the Water-Telescope.

1871. Observations of Z.D. of γ *Draconis* with the Water-Telescope.
1872. Observations of Z.D. of γ *Draconis* with the Water-Telescope.

VIII.—Measures of Double Stars with the Double-image Micrometer.

1840. Measures of distances and position-angles of 27 circumpolar double stars (with the view of remarking any exhibition of difference of annual parallax).
1842. Measures &c. of 3 double stars.
1843. Measures &c. of 2 double stars.
1844. Measures &c. of 3 double stars.

1846.	Three measures	of γ *Virginis*.
1847.	Two measures	
1848.	Two measures	
1849.	Three measures	
1850.	Four measures	
1851.	Three measures	
1852.	Three measures	
1853.	Two measures	
1855.	Two measures	
1856	Five measures	
1858.	Two measures	
1859.	One measure	

IX.—Observations for Star's Proper Motion and Parallax.

1847. Comparisons in R.A. and N.P.D. of Groombridge 1830 with a neighbouring star, made with N.E. Equatoreal.

X.—Variation of Brightness, and Spectroscopy, of Stars.

Vol. of *G.O.*

1848. Remarks on a variable star in *Ophiuchus*.
1864. Micrometric measures of lines in the spectra of the Sun and several principal stars, made in 1863.

XI.—Micrometric Observations of Solar Eclipses, with Complete Reductions.

1836. Observations &c. of the Solar Eclipse, 1836, May 15.
1845. Observations &c. of the Solar Eclipse, 1845, May 5.
1846. Observations &c. of the Solar Eclipse, 1846, April 25.
1858. Observations &c. of the Solar Eclipse, 1858, March 14–15.
1860. Observations &c. of the Solar Eclipse, 1860, July 18.
1870. Observations &c. of the Solar Eclipse, 1870, December 21–22.
1874. Observations &c. of the Solar Eclipse, 1874, October 9.
1875. Observations &c. of the Solar Eclipse, 1875, September 28–29.

XII.—Observations of Lunar Eclipses.

1838. (Introduction) Lunar Eclipses, 1837, April 20 and October 13.
1848. Observations of the Lunar Eclipses, 1848, March 19 and Sept. 12.
1856. Observations of the Lunar Eclipse, 1856, October 13.
1858. Observations of the Lunar Eclipse, 1858, February 27.
1860. Observations of the Lunar Eclipse, 1860, February 6.
1863. Observations of the Lunar Eclipse, 1863, June 1.

XIII.—Comparisons of Lunar Tables with Observations.

1856. Results of Lunar Observations, with corrected parallax, 1852 to 1855. (In continuation of the Great Lunar Reductions.)
1859. Comparison of observed places of the Moon with Burckhardt's and Hansen's Tables, 1847 to 1858.

XIV.—Extra-meridional Transits of the Moon for Measure of Diameter, compared with Burckhardt's Diameter.

(These Observations were made with the N.E. Equatoreal at the hour when the Moon was full in right ascension, with the telescope fixed in hour angle, in which state the duration of transit does not differ by $\frac{1}{20000}$ part from that on the meridian.)

1837. 27 transits on 2 days.
1838. 17 transits on 2 days.
1839. 33 transits on 4 days.
1840. 74 transits on 7 days.
1841. 10 transits on 1 day.
1842. 30 transits on 3 days.
1843. 13 transits on 2 days.
1844. 8 transits on 1 day.
1845. 17 transits on 3 days.
1846. 11 transits on 2 days.
1847. 13 transits on 2 days.
1848. 5 transits on 1 day.
1849. 8 transits on 2 days.
1850. 12 transits on 2 days.
1851. 6 transits on 1 day.

XV.—Deduction of the Moon's Diameter from observed Occultations.

Vol. of *G.O.*

1864. Deductions, by Hugh Breen, Esq., from reduced observations of Occultations of Stars at Cambridge and Greenwich, from 1830 to 1860.

XVI.—Lunar Theory.

1875. First part of Numerical Lunar Theory, by Sir G. B. Airy.

XVII.—Reduction of Ancient Observations of Planets.

1864. Complete reductions, by Hugh Breen, Esq., of all the observations of Planets made at the Royal Observatory from 1831 to 1835.

XVIII.—Corrections of the Orbital Elements in the Tables of Jupiter and Saturn.

1868. Investigation, by Hugh Breen, Esq., of the Corrections of the Elements given by the reduced Greenwich Observations from 1750 to 1865.

XIX.—Transits of Mercury over the Sun's Disk.

1845. Observations of the Transit of 1845, May 8.
1848. Observations of the Transit of 1848, November 8.
1868. Observations of the Transit of 1868, November 4.

XX.—Equatoreal Observations of Mars, East and West of Meridian, for Solar Parallax.

1862. Differential Observations of *Mars* and neighbouring stars, on both sides of the Meridian, from 1862, September 11 to October 24.

XXI.—Occultations of Planets by the Moon.

1854. Occultation of *Mars*, 1854, March 12.
1857. Occultation of *Jupiter*, 1857, January 2.

XXII.—Comparisons of the Places of Planets with those of Neighbouring Stars, by Equatoreal.

1836. Comparisons of *Venus* and *Saturn* with stars.
1837. Comparisons of *Mars* with stars.
1838. Comparisons of *Jupiter* with a star.
1839. Comparisons of *Mars* with stars.
1840. Comparisons of *Mars* with stars.
1841. Comparisons of *Mars* with stars.
1843. Comparisons of *Mars* with stars.
1845. Comparisons of *Astræa* and *Mars* with stars.
1846. Comparisons of *Neptune* with stars.
1849. Comparisons of *Mars* with stars.

XXIII.—Measures of the Diameters of Planets and of Saturn's Ring, with Double-image Micrometer.

1840. Measures of *Venus* (and her phases), *Jupiter*, *Saturn*.
1841. Measures of *Mercury*, *Venus*, *Mars*, *Jupiter*, *Saturn*.
1842. Measures of *Mars*, *Venus*, *Jupiter*, *Saturn*.
1843. Measures of *Venus*, *Mars*, *Jupiter* (with transits of *Saturn*).

Vol. of *G.O.*

1844. Measures of *Mercury, Venus, Jupiter.*
1845. Measures of *Mercury, Venus, Mars, Jupiter.*
1846. Measures of *Jupiter, Saturn, Neptune.*
1847. Measures of *Venus, Mars, Jupiter.*
1848. Measures of *Jupiter, Saturn, Uranus.*
1849. Measures of *Venus, Jupiter, Saturn.*
1851. Measures of *Jupiter.*
1852. Measures of *Venus, Mars, Saturn.*
1854. Measures of *Saturn.*
1855. Measures of *Saturn.*
1856. Measures of *Venus, Mars, Jupiter, Saturn* (and his rings).
1857. Measures of *Venus, Jupiter, Saturn.*
1858. Measures of *Mercury, Mars, Jupiter.*
1859. Measures of *Jupiter, Saturn.*
1860. Measures of *Jupiter, Saturn.*
1861. Measures of *Saturn.*

XXIV.—Remarks on the Surfaces of Planets.

1845. Examination of the Surface of *Mars.*
1848. Remarks on *Saturn.*

XXV.—Measures of the Positions of Satellites relative to their Primaries.

1836. Transits of *Jupiter* and his 4th Satellite, terminating the series of Observations for the Mass of *Jupiter.*
1875. Micrometric measures of the Positions of *Saturn's* Satellites.

XXVI.—Equatoreal Comparisons of the Places of Comets with those of Stars, and Remarks on the Appearance of Comets.

1838. Encke's Periodical Comet with stars, and remarks on its appearance (1838).
1839. Galle's first Comet (1840, I).
1840. Galle's second Comet (1840, II).
Bremicker's Comet (1840, IV).
1842. Encke's Periodical Comet (1842, I)
Laugier's Comet (1842, II).
1843. Appearance of the Great Comet (1843, I).
Mauvais' first Comet (1843, II).
Faye's Periodical Comet (1843, III).
1844. Mauvais' second Comet (1844, II).
De Vico's first (Periodical) Comet (1844, I).
1845. D'Arrest's Comet (1845, I).
Wilmot's Comet (1844, III).
De Vico's second Comet (1845, II).
Colla's Comet (1845, III).
Biela's Periodical Comet (1846, II).
1846. Brorsen's Periodical Comet (1846, III).
Brorsen's second Comet (1846, VII).
De Vico's third Comet (1846, I).
De Vico's fourth Comet (1846, IV).
De Vico's fifth Comet (1846, V).
1847. Hind's second Comet (1847, I).
1848. Encke's Periodical Comet (1848, II).
1852. Encke's Periodical Comet (1852, I).
1854. Second Comet of this year (1854, II).

Vol. of *G.O.*

1857. Brorsen's Periodical Comet (1857, II).
1858. Appearance of Donati's Comet (1858, VI).
1861. Second or Great Comet (1861, II).
1873. Tempel's first Periodical Comet (1873, I).

XXVII.—Operations for Terrestrial Longitude.

1845. Determination of the Longitude of Valentia, by Transmission of Chronometers.
1862. Determination of the Longitude of Valentia, by Galvanic Signals.

XXVIII.—Ancient Magnetic Observations.

1869. Reprint of Halley's Magnetic Chart.

XXIX.—Lithographic Copies of Photographic Records made by Magnetical and Meteorological Instruments.

1872. Lithographed Copies of Photographic Records of Magnetic Declination, Horizontal Force, Vertical Force, and Earth Currents, for 1872, February 4.

XXX.—Reductions of Modern Magnetic Observations.

1859. Reduction of Magnetic Observations, 1848–1857, with reference to positions of Sun and Moon.
1862. Abstracts of the Magnetic Observations made on Days of Great Magnetic Disturbance, 1841–1857.
1867. Reduction of Magnetic Observations, 1858–1863, with reference to positions of Sun and Moon.

XXXI.—Barometric Variations.

1867. Diagram of Barometric Variations, 1867, October 26 to December 11.

XXXII.—Observations of Thermometers sunk deep in the Ground.

1860. Reduction by Professor Everett of the Observations of the Deep-sunk Thermometers, 1846-1859.

XXXIII.—Observations of an Earthquake.

1863. Observations of the Earthquake of 1863, October 5.

The following works have been issued from the Royal Observatory, but are not bound as Appendixes to the *Greenwich Observations*:—

Eiffe and Molyneux on Chronometers.
Groombridge's Catalogue of Stars.
Planetary Reductions, 1750 to 1830.
Lunar Reductions, 1750 to 1830 (two volumes).
„ „ 1831 to 1851 (one volume).
Reduction of Fallows' Observations at the Cape of Good Hope.
Report on the Telescopic Observations of the Transit of *Venus*, 1874.
Reduction of Greenwich Meteorological Observations, viz.:—
Barometer, 1854-1873;
Air and Moisture Thermometers, 1849–1868.
Earth Thermometers, 1847–1873.

On the Apparent Colours of Mars and Saturn, as seen at their approach on 1879, June 29, observed at Glasgow, Missouri, United States.

(*In a letter from Professor C. W. Pritchett, Superintendent of the Morrison Observatory, Glasgow, to the Astronomer Royal, dated 1879, July 29.*)

1879, June 29, Glasgow mean astronomical time.
Lat. 39° 16 16″·75; Long. from Greenwich 6^h 11^m $18^s·9$.

$14^h·5$—15^h. Spent some time in looking at the planets *Saturn* and *Mars* in their very near approach. In the finder of $3\frac{1}{2}$ inches aperture both appeared at once—*Mars* with his usual *ruddy* glow and *Saturn* tinged with a *greenish* hue, which was more and more manifested to be in great part *subjective*, or the *effect of contrast*. In the large telescope, with a micrometer eye-piece of 150, they could not both be seen at once. A separate examination showed *Saturn* with his ring very distinct, three satellites east and south, and one north and west. *Mars* was gibbous and well defined, with his fiery red glare on the illuminated side, and a tinge of green on the defective limb. Always, after looking at *Mars* for some minutes, when the eye was nearly turned on *Saturn*, a reddish tinge was observed which gradually disappeared, showing (I think) that the overmastering power of the light of *Mars* caused such an impression on the optic nerve as to last long enough to produce a purely subjective effect.

Next, a low power eye-piece, of 50, was screwed into the tube; and both planets were readily brought into the same field. The effect of colours then became more apparent. The illuminated surface of *Mars* was clearly defined and ruddy, while *Saturn* showed his usual dull white light; but whenever the eye passed rapidly from *Mars* to *Saturn*, the latter (especially near the centre of the disk) always showed for a few seconds a decidedly reddish tint. It was a rare and grand sight to have both these planets in the same field with a fine objective of $12\frac{1}{4}$ inches, and I parted with the view with reluctance as one I may never have again. The planets were afterwards examined under an eye-piece of 275. As the morning was fine they presented a splendid appearance. They were now so far out of the field as to produce no *subjective* effect as before. No measures were attempted, as my hand and arm were disabled. Arrangements were made to examine the planets on the morning of June 30, M. Ast. Time, but clouds prevented.

Note on the Transit of the Earth and Moon across the Sun's Disk as seen from Mars on November 12, 1879, and on some kindred Phenomena. By A. Marth, Esq.

At the meeting of the Society in November last I mentioned that on the day of the next opposition of the planet *Mars*, the Earth and Moon, as seen from *Mars*, would cross the Sun's disk, a phenomenon which had not happened since the year 1800, and I stated the chief circumstances connected with the case. The following data will sufficiently indicate the course of the two bodies across the disk:—

Ingress.				Egress.			
1879 Nov. 12. G.M.T. h m	Pos. angle. °			G.M.T. h m	Pos. angle. °		
1 49	125·7	external contact of	☾	9 40	225·3	internal contact of	☾
1 55	126·4	internal ,,	,,	9 46	226·1	external ,,	,,
4 16	123·3	external ,,	♁	11 39	225·9	internal ,,	♁
4 37	125·9	internal ,,	,,	12 0	228·5	external ,,	,,

The apparent radius of the Sun's disk may be taken to be 650″·5, that of the Earth 18″·1, that of the Moon 4″·9. The position-angles are reckoned from the point of the Sun's disk in the direction of the north pole of the orbit of *Mars*.

The last occasion when the Earth and Moon crossed the Sun's disk for *Mars* occurred on November 8, 1800. The two next transits, near the opposite node, will take place at the times of the oppositions in May 1905 and May 1984.

During the last half-century there have been *ten* transits of *Mercury* as seen from *Mars* (against *six* as seen from the Earth):

1836 July 27	1856 June 4*
37 Aug. 23*	57 April 15
38 July 3 (very short chord)	66 Sept. 5
47 Jan. 13*	76 Jan. 27
47 Nov. 23	77 Feb. 21*

the four marked with an asterisk being near the descending node, the others near the ascending node of the orbit of *Mercury* on that of *Mars*.

Venus has crossed the Sun's disk four times:

1830 May 15	1862 May 15
34 Dec. 27*	66 Dec. 25*

On the other hand, *Mars* itself has crossed the Sun's disk, as seen from *Saturn* or *Saturn's* satellites, 1831, July 25 (short chord), and 1847, July 26. It has been in transit for *Uranus* and its satellites 1851, July 25, and 1853, June 24 (apparent diameter of Sun 97″·4, of ♂ 0″·5), and for *Neptune* and its satellite 1860, October 25, and 1862, September 19, (apparent diameter of Sun 64″·4, of ♂ 0″·3). The reason that there have not been more transits for *Neptune* than for *Uranus* is found in the cir-

cumstance that the inclination of the orbit of *Mars* to that of *Neptune* is double that of the orbit of *Mars* to that of *Uranus*. Otherwise transits will in general be the more frequent, the further the outer planet is away. There has been no transit of *Mars* for *Jupiter* and *Jupiter's* satellites during the last half-century. The last transit occurred August 13, 1785, the next one will take place, I presume, in April 1886.

Though these statements respecting transits across the Sun's disk, as seen from or occasioned by the planet *Mars*, may possess no direct practical interest, they will perhaps facilitate the formation of correct and distinct notions concerning this class of invisible phenomena, and their communication may therefore not be without interest for some readers.

On the Change in the Mean Error of Longitude of Hansen's Lunar Tables since 1876. By W. T. Lynn, B.A.

At page 12 of his last Annual Report to the Board of Visitors, the Astronomer Royal expressed the opinion that the error of longitude of Hansen's Lunar Tables, instead of continuing to increase as it had done for several years previously, was on the whole somewhat smaller in 1878 than it had been a year or two before. I have put this to the test of figures, by computing the mean error from the Greenwich observations made with both the Transit-Circle and Altazimuth in 1878, and comparing it with that from the observations in 1876, as given in my paper in the *Monthly Notices* for last March (page 369). The Astronomer Royal gives me permission to make public the result from the observations for 1878, which are not yet published, and I am thereby enabled to exhibit the following comparison, proving that the mean error of longitude was in fact then decreasing, as it probably is still :—

1. From Observations with the Transit-Circle—

Year.	No. of Observations.	Mean Error of Longitude for the Year.
1876	82	$+9''.72$
1878	90	$+8''.23$

2. From Observations with the Altazimuth—

Year.	No. of Observations.	Mean Error of Longitude for the Year.
1876	171	$+9''.31$
1878	161	$+7''.48$

The sign + indicates, as usual in the *Greenwich Observations*, that the *Nautical Almanac* (Hansen's) place is too large. The largest mean error in the opposite direction was in the year 1862, which is given in my paper above referred to, and amounts to about $-3''.20$ from the mean of the results with the two instruments. From that time it appears to have been affected

by a positive change of about one second annually, so as to become practically insensible in 1865–6, and then to increase regularly until it became nearly 10″ in 1876–77.

Mean Areas of Umbræ, Whole Spots, and Faculæ upon the Sun's Disk as measured on Photographs taken at the Royal Observatory, Greenwich, for each Rotation of the Sun from 1873, *July* 11.

(*Communicated by the Astronomer Royal.*)

The Mean Areas have been formed by taking the Means of the Areas for each day of observation throughout each rotation of the Sun, and are expressed in millionths of the Sun's visible hemisphere.

No. of Rotation.	Date of Commencement of each Rotation.	Mean Area.		
		Umbræ.	Whole Spots.	Faculæ.
1	1873 July 11	237	1308	3773
2	Aug. 6	118	683	4539
3	Aug. 31	78	460	4295
4	Sept. 25	153	798	3036
5	Oct. 21	107	668	1719
6	Nov. 15	37	244	1356
7	Dec. 11	80	583	1456
8	1874 Jan. 5	199	1172	3251
9	Jan. 30	51	318	1688
10	Feb. 25	47	426	436
11	Mar. 22	71	532	282
12	Apr. 16	54	488	60
13	May 12	38	291	259
14	June 6	39	436	513
15	July 2	174	1192	1519
16	July 27	206	1341	1963
17	Aug. 21	34	248	1906
18	Sept. 16	127	904	1645
19	Oct. 11	42	227	794
20	Nov. 6	60	437	773
21	Dec. 1	17	138	255
22	Dec. 26	17	99	1197
23	1875 Jan. 21	21	107	1069
24	Feb. 15	120	653	620
25	Mar. 12	56	321	643
26	Apr. 7	81	547	706
27	May 2	22	138	190

No. of Rotation	Date of Commencement of each Rotation.	Mean Area.		
		Umbræ.	Whole Spots.	Faculæ.
28	1875 May 28	65	420	274
29	June 22	90	485	365
30	July 17	20	129	327
31	Aug. 12	24	128	598
32	Sept. 6	14	96	383
33	Oct. 1	17	98	259
34	Oct. 27	29	130	212
35	Nov. 21	78	377	164
36	Dec. 17	16	96	113
37	1876 Jan. 11	50	302	226
38	Feb. 5	66	348	318
39	Mar. 2	57	248	510
40	Mar. 27	8	40	324
41	Apr. 21	9	38	267
42	May 17	0	0	62
43	June 11	8	41	251
44	July 7	12	51	225
45	Aug. 1	7	28	80
46	Aug. 26	7	34	265
47	Sept. 21	34	136	209
48	Oct. 16	27	147	235
49	Nov. 11	37	130	163
50	Dec. 6	44	334	144
51	1877 Jan. 1	41	186	345
52	Jan. 26	13	64	131
53	Feb. 20	18	92	85
54	Mar. 17	8	41	320
55	Apr. 12	34	157	192
56	May 7	22	95	255
57	June 2	16	73	126
58	June 27	5	18	188
59	July 22	1	5	30
60	Aug. 17	21	102	217
61	Sept. 11	6	33	199
62	Oct. 6	35	187	46
63	Nov. 1	52	239	184
64	Nov. 26	27	115	75
65	Dec. 22	0	5	128

Many of the photographs taken during the ninth and five following rotations, i.e., between 1874, January 30, and 1874, July 2, do not show the faculæ with sufficient distinctness to allow of their measurement; the mean areas of faculæ given for these rotations are therefore too small.

Mean Areas of Umbræ, Whole Spots, and Faculæ upon the Sun's Disk, as measured on Photographs taken at the Royal Observatory, Greenwich, for each Year, from 1873 to 1877.

The mean areas are expressed in millionths of the Sun's visible hemisphere.

Year.	Mean Area.		
	Umbræ.	Whole Spots.	Faculæ.
1873	116	678	2882
1874	83	582	1096
1875	45	255	475
1876	25	132	226
1877	20	94	168

Many of the photographs taken during the early part of 1874 do not show the faculæ with sufficient distinctness to allow of their measurement; the mean area of faculæ given for that year is therefore too small.

The mean area of faculæ for the half-year beginning 1874, July 2, is 1257.

Note on Hyperion. By Prof. Asaph Hall.

This faint satellite of *Saturn* has the most eccentric orbit of any known satellite, and its distance from *Saturn* is such that, combined with the large eccentricity, it can approach very near *Titan*, the largest satellite of the Saturnian system. This peculiar orbit of *Hyperion* renders its motion interesting, as it will be the means of giving us an accurate knowledge of the mass of the Ring and of *Titan*. My observations of *Hyperion* during the present year, 1878, seem to put it beyond doubt that the line of apsides of the orbit of *Hyperion* has revolved at least a semi-revolution, or 180°, since the time of the discovery of this satellite in 1848, by the Bonds and Lassell.

The only observations of *Hyperion* that I know of are those made by the Bonds in 1848, two or three observations by Professor G. P. Bond in 1849, the observations by Lassell* and Marth in 1864, and those made at Washington since 1874. The old observations of this satellite will be valuable for determining its time of revolution and the motion of the line of apsides. If other observations exist than those mentioned above, I shall be indebted to anyone who will inform me of them.

U.S. Naval Observatory, Washington,
1878, *December* 27.

* 1850, *Monthly Notices*, xi., p. 62; 1852, xiii., p. 181; 1860, xx., p. 292.—Ed.

Observations of Meteors made on November 27, 1878. By Lord Lindsay and Dr. R. Copeland.

Curr. No.	Observer.	G.M.T. h m s	Size.	Began. R.A. °	Began. δ °	Ended. R.A. °	Ended. δ °	Remarks.
1	R. C.	10 24 0	...	39·5	+38	39·5	+34	
2	R. C.	10 39 ±	...	15	+36	12·5	+35	
3	R. C.	10 49 ±	...	57·5	+32·5	41	+35	
4	R. C.	10 50 30 ±	...	...	...	...	...	In *Cancer*, moving to the left, downwards.
5	L.	10 55 ±	...	27	+22	5	+15	
6	R. C.	11 2 12	2	82	+24	68	+13·5	
7	R. C.	11 6 7	3	28·5	+42	14	+37·5	
8	R. C.	11 8 50	...	...	...	...	...	Seen in *Gemini*.
9	R. C.	11 9 55	4	43	+28	50	+31	Path uncertain.
10	L.	11 27 0	2	57·5	−14	74	−23	
11	R. C.	11 55 50	...	65	+17	33	− 4	Path uncertain.
12	L.	11 59 ±	...	57	+32	40	+29	Path somewhat uncertain.
13	R. C.	12 17 35	...	...	...	...	...	Seen in *Ursa Majoris*.
14	R. C.	12 20 5	...	...	...	...	...	Seen in *Leo*.
15	R. C.	12 21 30	...	...	...	...	...	Seen in *Leo Minor*.

16	L.	12	21	45	...	76	+46	110	+35	
17	R. C.	12	28	20	2	112	+31	131	+48	
18	L.	...		...	...	...	...	...	...	Seen.
19	L.	12	28	59	2	48	+49	43	+ 4	Moved on this line.
20	L.	12	36	35	...	79	+28·5	...	...	Nearly stationary; moved in direction 135° of position.
21	R. C.	12	42	29	3	106	+15	115	+12	
22	L.	12	44	45	...	66	+45	52	+43·5	Path about 10° long.
23	R. C.	12	50	30	3	105	+ 6	93·5	0	
24	L., R. C.	16	50±		...	130	− 1	148	+ 2	
25	L., R. C.	16	52	0	1	113	+ 6	117	− 4	
26	L., R. C.	16	55	40	2	11	+62	11	+54	
27	L.	17	1	33	3	82	+45	77	+48	
28	R. C.	17	1	51	2	84	+40	90	+35	
29	L.	17	3	45	...	15	+35	11	+60	Moved on this line.
30	L., R. C.	17	8	48	...	114	+28	112	+23	
31	L.	17	9	32	...	222	+75	76	+46	Moved on this line.
32	L.	17	18	19	...	20	+88·5	12	+60	Moved on this line.
33	L.	17	26	22	...	20	+88·5	319	+62	Moved on this line.
34	C.	17	35	17	2	107·5	+22·5	97	+16	
35	L.	17	37	15	2	183	0	182	−16	

Observations of Meteors made on November 27, 1878—continued.

Curr. No.	Observer.	G.M.T. h	m	s	Size.	Began. R.A. °	δ °	Ended. R.A. °	δ °	Remarks.
36	R. C.	17	41	58	3	90	+42	85	+46·5	
37	L.	17	45	12	2	113	+. 6	83	− 3	Moved on this line.
38	R. C.	17	46	47	2	74	+53	67	+47	
39	L. C.	17	51	8	2	111	+65	111	+55	
40	L.	17	51	39	1	81·5	+21	66	+16	Slowish.
41	L.	17	54	30	3	81·5	+21	54	+24	
42	R. C.	17	55	35	2	45	+55	34	+48	
43	L.	17	56	10	3	11	+60	54	+24	Moved on this line.
44	R. C.	18	8	53	2	82	+53	70	+48	
45	R. C.	18	20±		2	...	...	...	...	In *Crater*, moving southwards.

15 meteors emanate from a diffused radiant, at R.A. 96°, Decl. +23°.
7 belong decidedly to Heis's No. 19 in 0° +90°.
37 paths were entered on the map which is in the B.A. Atlas.

Scarcely a single meteor was seen which could be attributed to the Biela radiant, but as the period of the comet is about 6 years and 202 days, a return of the meteors would hardly be considered probable. In 1885, November 27 will fall only forty days short of two periods since November 27, 1872, and will afford the best chance that can occur during the remainder of this century.

Dun Echt Observatory,
Nov. 29, 1878.

INDEX.

PAGE

Airy, Sir G. B., note on the determination of the mass of *Mars* 140
———— on the conjunction of *Mars* and *Saturn*, 1879, June 30 141
See Greenwich, Royal Observatory.
Anomaly, excentric, on formulæ for expression of, in terms of the mean anomaly, M. A. de Gasparis 386
Ascension expedition, on progress of the reductions, Mr. Gill 51
———— observations of *α Centauri* with the heliometer at, the same ... 123
———— the solar parallax derived from observations of the opposition of *Mars*, 1877, at, the same..... 434
Associates elected 149
Associate deceased, Secchi, A..... 238
Åstrand, two short and easy methods for correcting lunar distances 425
Astronomy, report on the progress of, in the year 1878–79 :—
Prof. Newcomb's researches on the Moon's motion 256
Mr. Hill's researches on the lunar theory 258
Mr. Darwin's investigation of the influence of geological changes on the Earth's axis of rotation 260
Total solar eclipse of 1878, July 29 261
Reduction of the observations of the transit of *Venus* of 1874 262
Elements of *Vulcan* 263
Discovery of minor planets..... 264
Discovery of comets 265
Schmidt's "Charte der Gebirge des Mondes" ..... *ib.*
Lohrmann's "Mondcharte"..... 266
Publications of the Astronomical Observatory of Harvard College 267
Mr. C. S. Peirce's photometric researches 270
Double star observations of the Lund Observatory 274
Report on the progress of meteoric astronomy in the year 1878 by Prof. A. S. Herschel..... 275

Babylonian astronomy, preliminary paper on, Messrs. Bosanquet and Sayce 454
Backhouse, T. W., on the spectrum of the new star in *Cygnus* 34
Bessel's mean refractions in the *Fundamenta*, their applicability to the Washington observations, Mr. Downing..... 465
Bigg-Wither, Capt., explanation in regard to his observation of the transit of *Venus* 200
Birmingham, J., note on Gruithuisen's lunar crater *Schroeter* 432
Bosanquet, R. H. M., and Prof. Sayce, preliminary paper on the Babylonian astronomy 454
Bouvard, on observed errors of his tables of *Saturn*, Mr. Dunkin..... 172
Burnham, S. W., double star observations made in 1877-78 at Chicago with the 18½-inch refractor of the Dearborn Observatory, comprising : I. A catalogue of 251 double stars ; II. Micrometrical measures of 500 double stars. (Abstract) 76

PAGE

Carpmael, C., on the values of the constants in the equation ${}_rA_r x^{(r)} + \ldots + {}_rA_0 - y_x = 0$, obtained by the method of least squares from the $n+1$ values of y_x when $x = 0, 1, 2 \ldots n$; n being greater than r 489
Catalogue, Cape, for 1860, reduction of N.P.D.'s to Auwers' standard, Mr. Downing 133
——— Melbourne, first general, for 1870, reduction of N.P.D.'s to Auwers' standard, the same 174
——— errata in, Mr. Ellery ... 488
——— Ulugh Beigh's, of stars, on a Persian MS. of, Mr. Knobel 337
Chazal, M. E. de, announcement by President of his decease 373
Christie, W. H. M., on a phenomenon seen in the occultation of a star by the Moon's bright limb 198
Chronometers, on Hartnup's method of testing, Mr. Nevins 325
Comets:
Tempel's, 1878, Prof. Pritchard 75
Encke's, 1878, Mr. Tebbutt 75, 321
Brorsen's, on spectrum of, observed at Greenwich 428
——— observations of, Lord Lindsay 430
——— Mr. Tebbutt 430, 486
——— Mr. Russell 431
Common, A. A., on the desirability of photographing *Saturn* and *Mars* at the next conjunction 381
——— note on large telescopes, with suggestions for mounting reflectors 382
Conic orbit, on law of force in, Mr. Glaisher 77
Copeland, Dr. R., and Lord Lindsay, note on some hitherto unnoticed features near the lunar crater *Hyginus* 195
——— observations of meteors, 1878, November 27 518
Council, extract from minutes of, 1879, May 9 389

Denning, W. F., meteor showers derived from foreign observations 22
——— the radiant points of April 9–12 402
——— a catalogue of 222 stationary meteors 406
Diaphragm, a variable, for solar and sidereal observations, Mr. Levander 199
Downing, A. W., reduction of the North Polar Distances of the Cape Catalogue for 1860 to Auwers' standard 133
——— on the reduction of the North Polar Distances of the First Melbourne General Catalogue for 1870 to Auwers' standard 174
——— on the applicability of the mean refractions of Bessel's *Fundamenta* to the Washington observations 465
Draper, Dr. H., on the coincidence of the bright lines of the oxygen spectrum with bright lines in the solar spectrum 440
Dreyer, J. L. E., an apparently new variable star 374
Driving clocks, an invention for giving perfectly uniform rotation in, Mr. Russell 462
——— a new method of controlling, Mr. Johnson 486
Dunkin, E., on the observed errors of Bouvard's tables of *Saturn* 172

Eclipses:
Lunar of 1877, February 27, Mr. Todd 19
Solar of 1878, February 2, the same 21
——— July 29, Dr. Schuster 44
——— Mr. Penrose 48
——— Mr. Pickering 137
Ellery, R. L. J., errata in First Melbourne General Catalogue, 1870 488

PAGE
Elliptic motion, disturbed, the general problem of, Mr. Neison 149
Errata 200, 388, 528

Fellows deceased, list of 216
Bonomi, J. ..... *ib.*
Booth, Rev. J. 219
Cooper, W. R. 225
Ellis, H. S. ..... *ib.*
Holmes, Dr. P. 226
Johnson, H. 227
Main, Rev. R. ..... *ib.*
Matheson, J. 235
Nichol, J. W. 237
Pigott, G. G. G. F. ..... *ib.*
Vernon, G. V. 238
Fellows elected 1, 77, 149, 201, 321, 373, 389, 433

Gasparis, M. A. de, on some formulæ for expressing the value of the excentric anomaly etc. in terms of the mean anomaly 386
Gill, D., on the progress of the reductions connected with the Ascension expedition 51
——— on the results of meridian observations of the *Mars* comparison stars 98
——— on observations of *α Centauri* made with the heliometer at Ascension in 1877 123
——— note on some remarks of Mr. Maxwell Hall on the opposition of *Mars* 171
——— a new method of determining astronomical refractions 366
——— on the value of the solar parallax derived from observations of *Mars* made at Ascension Island during the opposition of 1877 434
Glaisher, J. W. L., on the law of force to any point in the plane of motion in order that the orbit may be always a conic 77
Gore, J. E., on a new variable star, *t Andromedæ* 199
Grant, Prof. R., observations of the transit of *Mercury*, May 6, 1878, and of occultation of *Mars* by the Moon, June 3, 1878, made at the Glasgow Observatory 167
Green, N. E., the approaching opposition of *Mars* 433
Greenwich, Royal Observatory, observations of occultations of stars by the Moon, and of phenomena of *Jupiter's* satellites, in the year 1878 178
——— on the spectrum of Brorsen's comet 428
——— index to records of occasional observations and calculations in the annual volumes 1836 to 1875, with list of other publications of the Royal Observatory 505
——— mean areas of umbræ, whole spots, and faculæ upon the Sun's disk as measured on photographs taken at the Observatory for each rotation of the Sun from 1873, July 11 515

Hall, Prof. A., extract from a letter to the Astronomer Royal 373
——— President's address on presentation to him of the medal ... 306
——— note on *Hyperion* 517
Hall, M., addition to memoir on the theory of the sidereal system 126
——— his paper on opposition of *Mars*, remarks on, Mr. Gill 171
Hansen's secular acceleration, on Newcomb's correction to, Mr. Neison ... 72
——— coefficient of annual equation, on correction to, the same 394
——— lunar tables, on change in the errors of, between 1848 and 1876, Mr. Lynn 368

PAGE

Hansen's lunar tables, on change in mean errors of longitude in, since 1876, Mr. Lynn 514
Hartnup, on his method of testing chronometers, Mr. Nevins 325
Herschel, Sir J., his reference catalogue of double stars, Prof. Pritchard 390

Interpolation, *see* Carpmael, on the values &c. 489

Johnson, R. C., a new method of controlling the driving clock of an equatoreal 486
Jupiter, physical appearance of, 1877, Mr. Todd 18
——— ephemeris for physical observations of, 1879, Mr. Marth 379
Jupiter's satellites:—
Phenomena of, 1877 Mr. Todd 3
——————— 1877-8, at Stonyhurst, Mr. Perry 177
——————— 1878, Greenwich, Royal Observatory 178

Knobel, E. B., notes on a Persian MS. of Ulugh Beigh's catalogue of stars belonging to the Royal Astronomical Society 337
Krueger, Prof., a formula for reducing precession in right ascension and declination from Bessel's to Struve's constants 364

Levander, F. W., on a variable diaphragm for use in solar and sidereal observations 199
Lindsay, Lord, announcement of the death of Mons. E. de Chazal 373
——————— observations of Brorsen's comet 430
——————— and Copeland, Dr. R., note on some hitherto unnoticed features near the lunar crater *Hyginus* 195
——————— ——————— observations of meteors, 1878, November 27 518
Liveing, E. H., on a portable star finder for altitude and azimuth telescopes 91
Longitudes of Berlin, Munich, Leipzig, Vienna, Paris, and Pulkowa, Dr. Oppolzer 438
Lunar distances, two short and easy methods for correction of, Mr. Åstrand 425
Lunar craters:—
Hyginus, Lord Lindsay and Dr. Copeland 195
Gruithuisen's *Schroeter*, Mr. Birmingham 432
Lunar theory and tables:—
On Neweomb's correction of Hansen's value of the secular acceleration, Mr. Neison 72
On correction to Hansen's coefficient of annual equation, the same ... 394
On change in the errors of Hansen's tables between 1848 and 1876, Mr. Lynn 368
On change in the errors of Hansen's tables since 1876, the same ... 514
Lynn, W. T., on the change in the errors of Hansen's lunar tables between 1848 and 1876 368
——————— note on η *Draconis* 371
——————— on the change in the mean errors of longitude in Hansen's lunar tables since 1876 514

Mars, comparison stars, results of meridian observations of, Mr. Gill ... 98
——— note on mass of, Sir G. B. Airy 140
——— occultation of, by the Moon, 1878, June 3, Prof. Grant 167
——— opposition of, remarks on Mr. M. Hall's paper on, Mr. Gill 171
——— the approaching opposition of (1879), Mr. Green 433
——— ephemeris for physical observations of, Mr. Marth 468
Mars and *Saturn*, on conjunction of, 1879, June 30, Sir G. B. Airy 141

PAGE

Mars and *Saturn*, on desirability of photographing at next conjunction, Mr. Common 381
———— on the colours of, Prof. Pritchet 512
Marth, A., ephemerides for determining the positions of the satellites of *Uranus*, 1879 181
———— ephemeris for physical observations of *Jupiter*, 1879 379
———— ephemeris for physical observations of *Mars* 468
———— note on the transit of the Earth and Moon across the Sun's disk as seen from *Mars* on November 12, 1879, and on some kindred phenomena 513
Mercury, transit of, 1878, May 6, Mr. Todd 21
———— Prof. Grant 167
———— measures of the diameter of, Prof. Young 168
Meteors:—
Meteor showers from foreign observations, Mr. Denning 161
Radiant-points of April 9–12, Mr. Denning 402
Catalogue of 222 stationary meteors, the same 406
Observations of 1878, November 27, Lord Lindsay and Dr. Copeland 518
Meteoric dust in the atmosphere, on the presence of, Mr. Ranyard 161
Moon, on photographic semi-diameter of, Prof. Pritchard 447

Nautical Almanac for 1882, corrections in 391
Neison, E., on Newcomb's correction to Hansen's value of the secular acceleration 72
———— on the general solution of the problem of disturbed elliptic motion 149
———— on the determination of the solar parallax from the parallactic inequalities in the longitude of the Moon, and on the correction to Hansen's coefficient of the annual equation 394
Nevins, A. E., on the practical advantages of Hartnup's method of testing chronometers 325
Newcomb, on his correction to Hansen's value of the secular acceleration, Mr. Neison 72

Observatories, accounts of proceedings of:—
Royal, Greenwich 242
Radcliffe, Oxford 244
University, Oxford 245
Cambridge 246
Dunsink, Dublin 247
Royal, Edinburgh 248
Kew 249
Liverpool ..... *ib.*
Temple, Rugby 250
Stonyhurst ..... *ib.*
Mr. Barclay's 251
Col. Cooper's ..... *ib.*
Mr. E. Crossley's 252
Mr. Huggins' ..... *ib.*
Earl of Rosse's ..... *ib.*
Col. Tomline's 253
Royal, Cape of Good Hope 254
Melbourne ..... *ib.*
Occultation of a star on the Moon's bright limb, on a phenomenon seen in, Mr. Christie 198
Occultations by the Moon:—
Mars, 1878, June 3, Prof. Grant 167
Stars, 1878, Royal Observatory, Greenwich 178

PAGE

Oppolzer, Dr., determination of the longitudes of Berlin, Munich, Leipzig, Vienna, Paris, and Pulkowa 438
Oxford University Observatory, account of new buildings and proceedings at, Prof. Pritchard 32
Oxygen, on probable presence of, in solar chromosphere, Dr. Schuster ... 388
——— spectrum, on coincidence of bright lines in, with those of solar spectrum, Dr. Draper 440

Pendulum, seconds, at St. Petersburg and other places in Western Russia, lengths of, corrected for flexures of Repsold's supports, Prof. Savitsch. (Abstract) 365
Penrose, F. C., the total eclipse of the Sun, July 29, 1878 48
Perry, Rev. S. J., phenomena of *Jupiter's* satellites, 1877–78, observed at Stonyhurst Observatory 177
Pickering, W. H., the total eclipse of the Sun, July 29, 1878 137
Poulkova observations, order of publication of successive volumes..... 390
Precession in R.A. and Decl., a formula for the reduction from Bessel's to Struve's constants, Prof. Krüger..... 364
Pritchard, Prof. C., account of additional buildings and of proceedings at the Oxford University Observatory 32
——————— observations of the periodic comet of Tempel, 1878 75
——————— note on Sir John Herschel's Reference Catalogue of Double Stars 390
——————— on the photographic semi-diameter of the Moon 447
Pritchett, Prof., on the colours of *Mars* and *Saturn* 512

Russell, H. C., observations of Brorsen's comet 431
——————— an invention for giving perfectly uniform rotary motion in driving clocks 462
Ranyard, A. C., note on the presence of particles of meteoric dust in the atmosphere 161
Refractions, astronomical, a new method of determining, Mr. Gill 366

Sadler, H., note on the late Admiral Smyth's "Cycle of Celestial Objects," volume the second, commonly known as the "Bedford Catalogue" 183
——————— remarks on his paper in the January number, Mr. Talmage 323
Safford, Prof. T. H., note on the star Bradley 2935 96
Saturn, observed errors of Bouvard's tables of, Mr. Dunkin 172
——— satellites of, note on *Hyperion*, Prof. Hall..... 517
Saturn and *Mars*, see *Mars* and *Saturn*.
Savitsch, Prof. A., lengths of the seconds pendulum at St. Petersburg and other places in Western Russia, corrected for the flexure of the supports constructed by M. Repsold. (Abstract) 365
Sayce, Prof. A. H. and Mr. Bosanquet, preliminary paper on the Babylonian astronomy 454
Schuster, Dr. A., some remarks on the total solar eclipse of July 29, 1878 44
——————— on the probable presence of oxygen in the solar chromosphere..... 388
Seabroke, G. M., spectroscopic observations of the motion of stars in the line of sight, made at the Temple Observatory, Rugby 450
Sidereal system, additions to memoir on, Mr. M. Hall 126
Smyth's, Admiral, Bedford Catalogue, notes on, Mr. Sadler 183
Smyth, Prof. Piazzi, measures of the great B line in the spectrum of a high Sun..... 38

PAGE

Society :—
Report of Council to fifty-ninth annual meeting 201
List of papers read from February 1878 to February 1879 297
List of donors to library &c. 302
President's address on delivery of medal to Prof. Asaph Hall..... 306
Election of officers and Council 319
Solar chromosphere, on probable presence of oxygen in, Dr. Schuster ... 388
Solar parallax, on the determination of, from parallactic inequalities in Moon's longitude, Mr. Neison 394
——————— value of, from observations of *Mars* at Ascension during opposition of, 1877, Mr. Gill 434
Solar surface :—
Mean areas of umbræ, whole spots, and faculæ upon the Sun's disk as measured on photographs taken at the Royal Observatory, Greenwich, for each rotation of the Sun from 1873, July 11 ... 514
Spectrum, solar :—
The great B line in spectrum of a high Sun, Prof. P. Smyth 38
On coincidence of bright lines in, with those of oxygen spectrum, Dr. Draper..... 440
Spectrum of new star in *Cygnus*, Mr. Backhouse 34
——————— Brorsen's comet, Greenwich, Royal Observatory 428
Spectroscopic observations of motion of stars in line of sight, Mr. Seabroke 450
Stars :—
Cygnus, new star in, spectrum of, Mr. Backhouse..... 34
Bradley 2935, Prof. Safford..... 96
α *Centauri*, observations of, with heliometer at Ascension in 1877, Mr. Gill 123
Pleiades, on visibility of stars in, to naked eye, Prof. Winnecke 146
η *Draconis*, note on, Mr. Lynn..... 371
An apparently new, Mr. Dreyer 374
Motion of, in line of sight, spectroscopic observations of, Mr. Seabroke 450
Stars, variable :—
ι *Andromedæ*, a new, Mr. Gore 198
Stars, double or multiple :—
Observations in 1877–78 at Chicago, comprising—I. Catalogue of 251 double stars; II. Micrometrical measures of 500 double stars; Mr. Burnham. (Abstract) 76
Star finder, a portable, for altitude and azimuth telescopes, Mr. Liveing 91
Stellar magnitudes, a request to astronomers, Prof. Pickering 391
Stone, E. J., extract of letter to the Astronomer Royal 433
Sun, observations of absorbing vapours on the Sun, Mr. Trouvelot 374

Talmage, C. G., remarks on Mr. Sadler's paper in the January number of the *Monthly Notices* 323
Tebbutt, J., observations of Encke's comet, 1878 75
——————— observations of Encke's comet, 1878 321
——————— observations of Brorsen's comet..... 430
——————— observation of Brorsen's comet, February and March 1879... 486
Telescopes, note on large, with suggestions for mounting reflectors, Mr. Common..... 382
Todd, C., observations at the Adelaide Observatory :—
Extract from letter to the Astronomer Royal 1
Phœnomena of *Jupiter's* satellites, 1877 3
Notes on Physical appearance of *Jupiter* &c. 18
Eclipse of the Moon, February 27, 1878 19
Partial eclipse of the Sun, February 2, 1878..... 21
Transit of *Mercury*, May 6, 1878 ..... *ib.*

PAGE

Transit of Earth and Moon across Sun's disk, as seen from *Mars* 1879, November 12, and kindred phenomena, Mr. Marth 513
Trouvelot, E. L., observations of absorbing vapours upon the Sun..... 374

Uranus, satellites of, ephemerides 1879, Mr. Marth 181
Ulugh Beigh, notes on a Persian MS. of his Catalogue of Stars, Mr. Knobel 337

Venus, transit of, explanation in regard to Capt. Bigg-Wither's observation of..... 200

Winnecke, Prof., on the visibility of stars in the *Pleiades* to the naked eye 146

Young, Prof. A. C., measures of the diameter of *Mercury*, made at the Princeton Observatory, May 6, 1878 168

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P. 37, line α, col. E of Table II., insert 581.
„ „ η, „ 3 „ III., for ·1 read ·15.

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LIST OF PRESENTS

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APPENDIX XXX.

To the Catalogue of the Library of the Royal Astronomical Society.

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